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Electrical Engineering Research Laboratory
The University of Texas

Austin, Texas

Report No. 6-52

28 February 1963

HIGH ALTITUDE MICROVARIATIONS WITHIN THE ATMOSPHERE'S RADIO REFRACTIVE-INDEX PROFILE

by

A. P. Deam
G. B. Walker

Contract AF 19(604)-8038
Project 5631
Task 563104

Prepared for
Electronics Research Directorate
Air Force Cambridge Research Laboratories
Office of Aerospace Research
United States Air Force
Bedford, Massachusetts

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This report presents observations of certain microscale fluctuations in the radio index of refraction of the earth's atmosphere. The measurements are unique in that the height profile has been continuously detailed to one part in a million with a remote operating 400 Mc/s refractometer. Data are insufficient to reach any statistical conclusion but are revealing in showing the turbulent structure within the height profile. A limited amount of data show the excursions in index observed to 50,000 feet.

I. INTRODUCTION

Crain,[1] as early as 1956, reported on airborne measurements of the micropulsations in radio index of refraction of the atmosphere. His recordings were made on strip chart recorders while the aircraft flew at arbitrarily selected altitudes up to 20,000 feet. From these data a measure of the quantity $\frac{(\Delta N)^2}{l}$ was obtained. He generally found that most of the observed variations occurred over distances in excess of 250 feet. The use of the refractometer in obtaining profiles was already well established. Other measurements have been made to as high an altitude as 43,000 feet but no extensive measurements of the fine structure have been made above 20,000 feet.[2]

Following Crain's work, this Laboratory developed a refractometer operating at 400 Mc/s.[3] It was designed as a radiosonde type of instrument, being of light weight and battery powered where the transmitted frequency changes directly with index of refraction within the cavity sensor. Remote measurement is thus made simple with a phase-lock type of receiver. The question naturally arises as to whether this instrument can be used to obtain a one dimensional refractive index power spectra - at altitudes say as high as 50,000 feet. Such high altitude direct measurements have been lacking in "scatter" propagation theoretical studies.

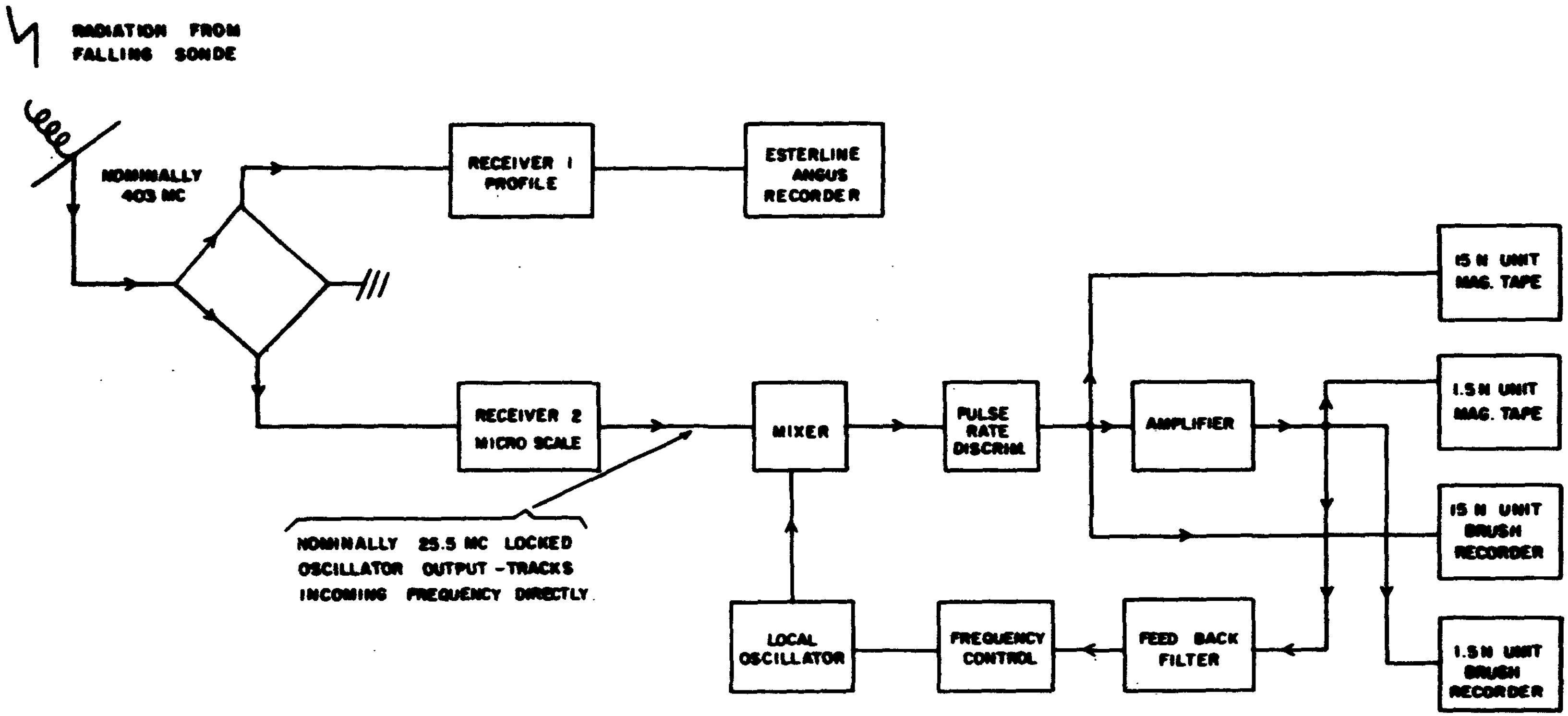
Accordingly, one refractometer was elevated with an over-inflated 800 gram neoprene balloon; useful data were recorded to an altitude of 40,000 feet. For reasons to be discussed later this type of experiment was discontinued. Through the excellent cooperation of the Balloon R and D Test Branch, AFCRL, Holloman Air Force Base, a package of four refractometers was flown on a semi-controlled trajectory at approximately 50,000 feet. Command ejection of each unit was arranged and two such units were successfully dropped. The success of this venture is discussed in the following text. The most difficult part of this experiment is obtaining the desired trajectory, particularly if it is desired that several units be dropped in sequence. Data were obtained on three separate occasions. Microscale variations were recorded continuously and jointly with the height refractive index profile of two occasions. In the remaining experiment, profile data only were obtained.

It was initially intended that the results of this work would be mainly related to small magnitude variations around the mean profile. It turns out that it has also produced some rather valuable information on the correction of height profile data to remove cavity temperature effects.

II. SYSTEM

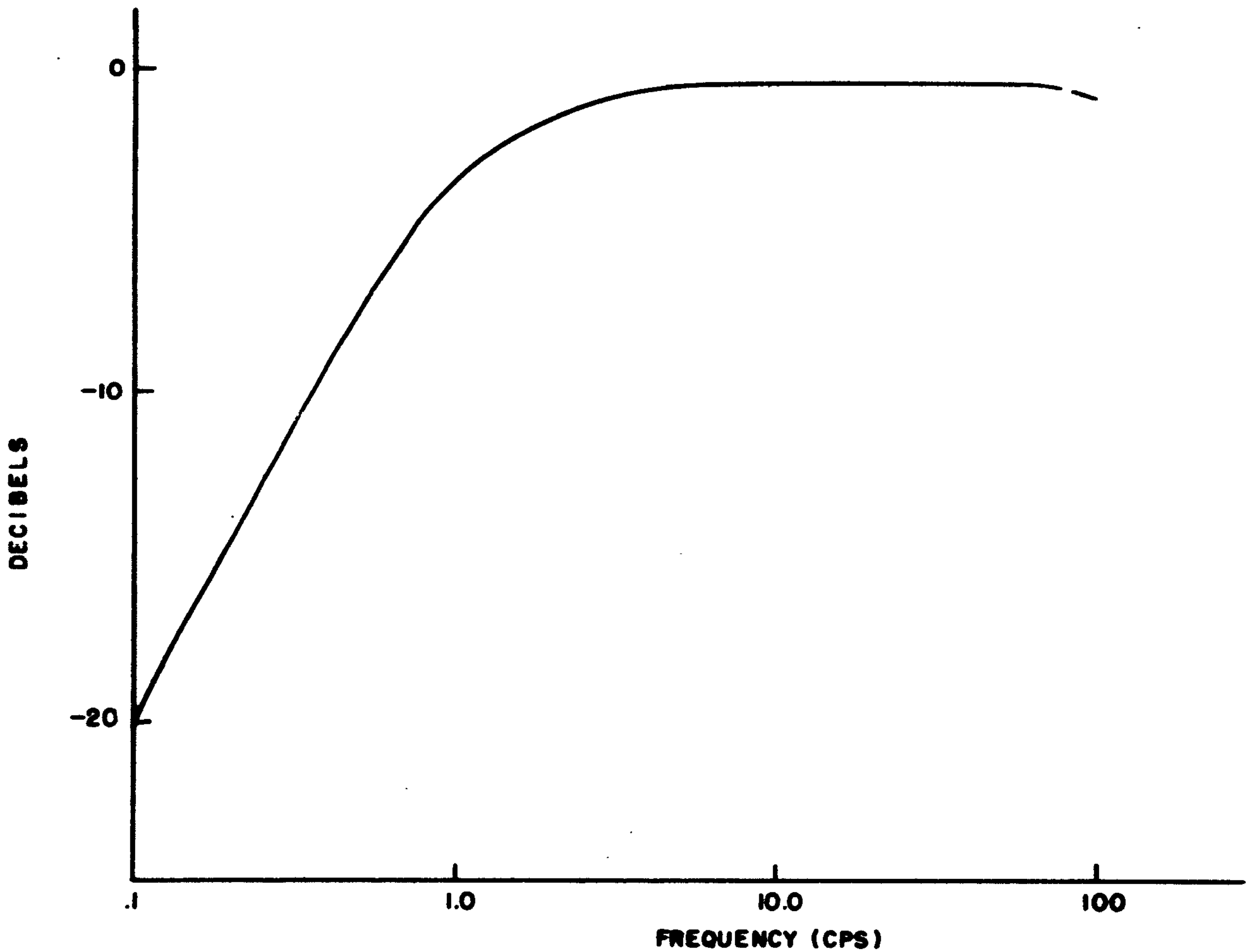
For the two experiments reported here, there is little difference in the equipment used. The refractometers were modified in both cases to be compatible with the experiment and involved only the manner in which the refractometer parachute was rigged and programmed.

The refractometers and the receiver have been well covered in the literature.[3] Electrically there was no change in the refractometers, although certain additions and changes were necessary in the phase-lock receiver in order to record the small scale variations within the height profiles. A block diagram of the receiver system is included as Fig. 1. The receiver recording the height profile was used exactly in the normal manner. From the second receiver a voltage was taken whose frequency followed the incoming frequency from the refractometer. This frequency was translated and counted with the pulse rate discriminator so that a full scale width of 800 cps (2 N units) was obtained at the Brush and magnetic tape recorders. Response of the feedback circuit determined the lower end of the information bandwidth and the upper end was fixed by the sampling process at the refractometer. Fig. 2 shows the response of the feedback



BLOCK DIAGRAM – RECEIVER

FIG. 1.



FREQUENCY RESPONSE OF FLUCTUATION RECEIVER

FIG. 2.

circuits as recorded on the Brush recorder. The response of the sampling cavity within the refractometer extends to space wavelengths that are the length of the cavity -- 14 inches.

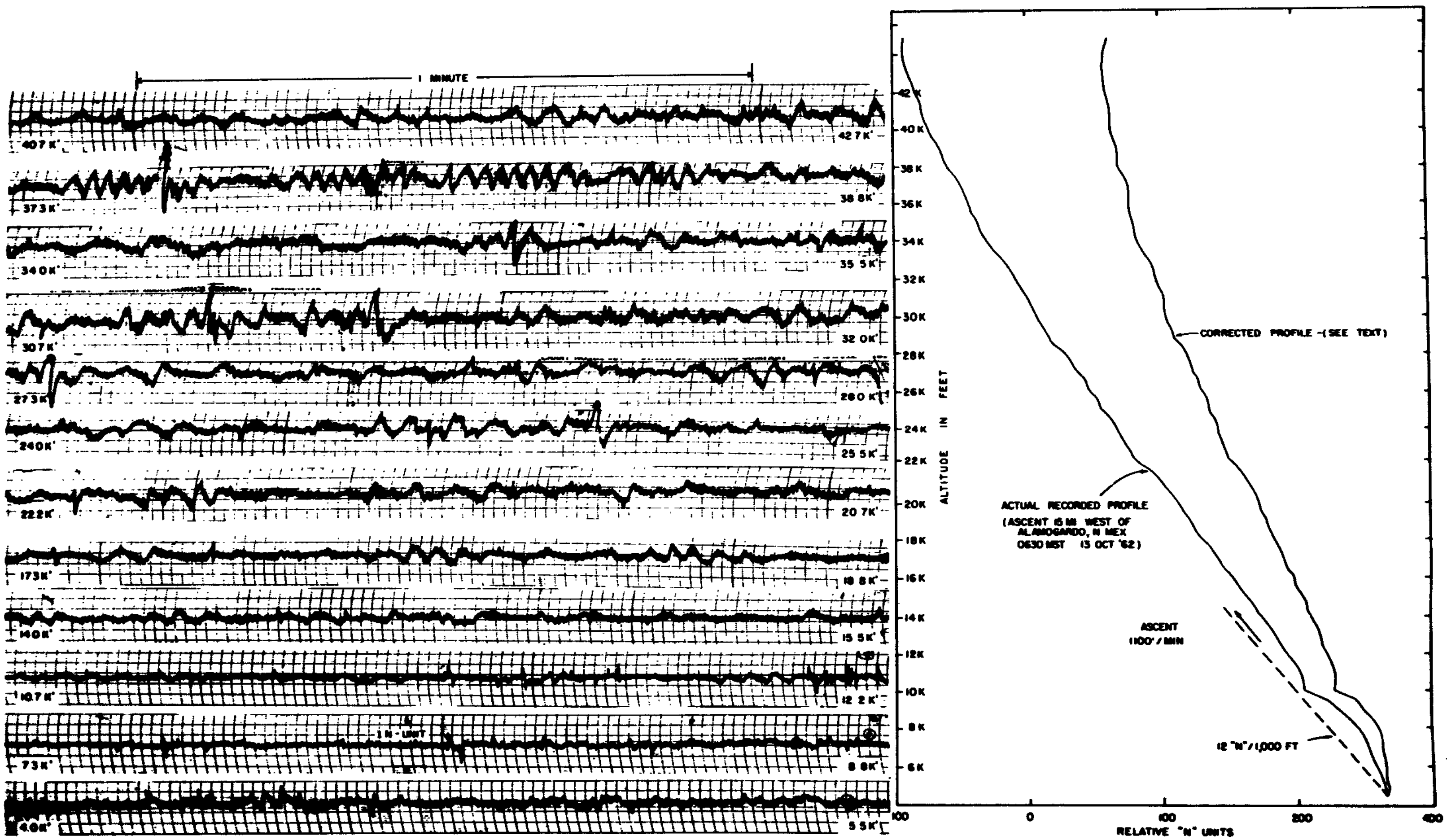
The threshold of operation for the profile receiver is near 125 dbm. The signal maintained in the system was approximately 20 db higher than this in order that adequate signal-to-noise ratio be present in the channel recording the microscale variations.

III. DISCUSSION OF THE DATA

Data are presented in the form of graphs and strip chart (Brush) recordings where the graphs are the smoothed profile and the chart shows the small scale variations. Since small scale variations were obtained on tape for only one refractometer sounding, there is a resulting variation in the manner in which the data are presented.

A. 800 Gram Balloon Ascension

Fig. 3 contains profile and microscale data obtained by elevating the refractometer with an over-inflated 800 gram neoprene balloon. It was anticipated that the balloon would reach 35,000 feet and the baroswitch was set to detach the balloon from the parachute at this altitude. The diameter of the parachute was six feet and was connected to the balloon with a nylon line 70 feet long. Knowing that there would exist oscillations in the package, the length of the line was cut to this



MICRO-VARIATIONS WITHIN PROFILE

FIG 3

length in the hope that the period would be satisfactorily eliminated by the feedback circuit indicated in Fig. 1. The rate of ascent was approximately 1100 feet per minute.

Insofar as the small scale fluctuations are concerned, there are two regions of interest -- that below about 15,000 feet and that above this altitude. The region below 15,000 feet is in agreement with what has been measured before; that is, the fluctuations damp out fairly rapidly with increasing altitude. Above 15,000 feet, there is a tendency for the fluctuations to increase to a value, say, of the order 0.5 N unit peak to peak. This is contrary to what one would have expected and opens the door to speculation as to the origin of the variations.

Rather thorough checking after the sounding was obtained indicated that the receiver was operating properly. Therefore, it would appear that the variations are actual frequency variations at the input to the receiver and generated by the 400 Mc/s refractometer.

The refractometer attempts to maintain, on the average, a minimum difference between the carrier frequency (400 Mc/s nominal) and the resonant frequency of the cavity resonator sampling the atmosphere. This is accomplished through a feedback system of finite gain which is dependent upon power supply voltages. Since the carrier generator must have a spectrum in part determined by acceleration forces, then this spectrum is in general determined by the refractometer motion below the balloon.

Then if, as the balloon rises to high altitudes, loss in loop gain results from battery fatigue, it is possible that the spectra introduced in the carrier by acceleration forces will become more apparent at the receiver as time or altitude increases. Thus, the validity of the microvariations, above about 15,000 feet as shown in Fig. 3 is questionable.

One qualitative observation that may be made, however, if it is assumed that the variations are falsely induced, is that the data should be filtered to remove the very pronounced period. Under these conditions the remaining signal would be about the same order of magnitude as that encountered between 10,000 and 12,000 feet.

The high frequency noise appearing on this chart is 60 cps and does not originate in the radiosonde. When this is removed, by filtering, it is found that the receiver noise is less than $\frac{1}{40}$ N unit peak to peak.

No conclusive evidence was found in later experiments to support or dispute the presence of the strongly periodic variations at the high altitudes. The fact remains that there was occasionally a driving "force" of highly periodic nature existing at the refractometer. By visually observing the refractometer with a theodolite, at lower altitudes, much longer periods of mechanical oscillation were observed.

These data were not acquired on magnetic tape because the tape was being held in readiness for the drop. Unfortunately, the balloon did not release and the whole package soared to near 70,000 feet. Signal strength was lost near 40,000 feet.

The profile was recorded through another channel and was read from the Esterline-Angus recording. A plot is made of the actual recorded profile and then this profile is corrected for temperature.[4] As the cavities have a relatively small time constant (1 minute) at the surface, it is a very good assumption to say that the cavity follows the average temperature profile which was taken as 3.6°F per 1000 feet. The cavity temperature coefficient had been previously determined to be 1 ppm/°F. It is considered that the resultant profile is in good agreement with a mean profile with the possible exception of near the surface where a temperature inversion appears to exist. The smoothed profile is not as critically related to the loss of loop gain in the refractometer as are the microvariations.

These data were obtained on a cloudless day.

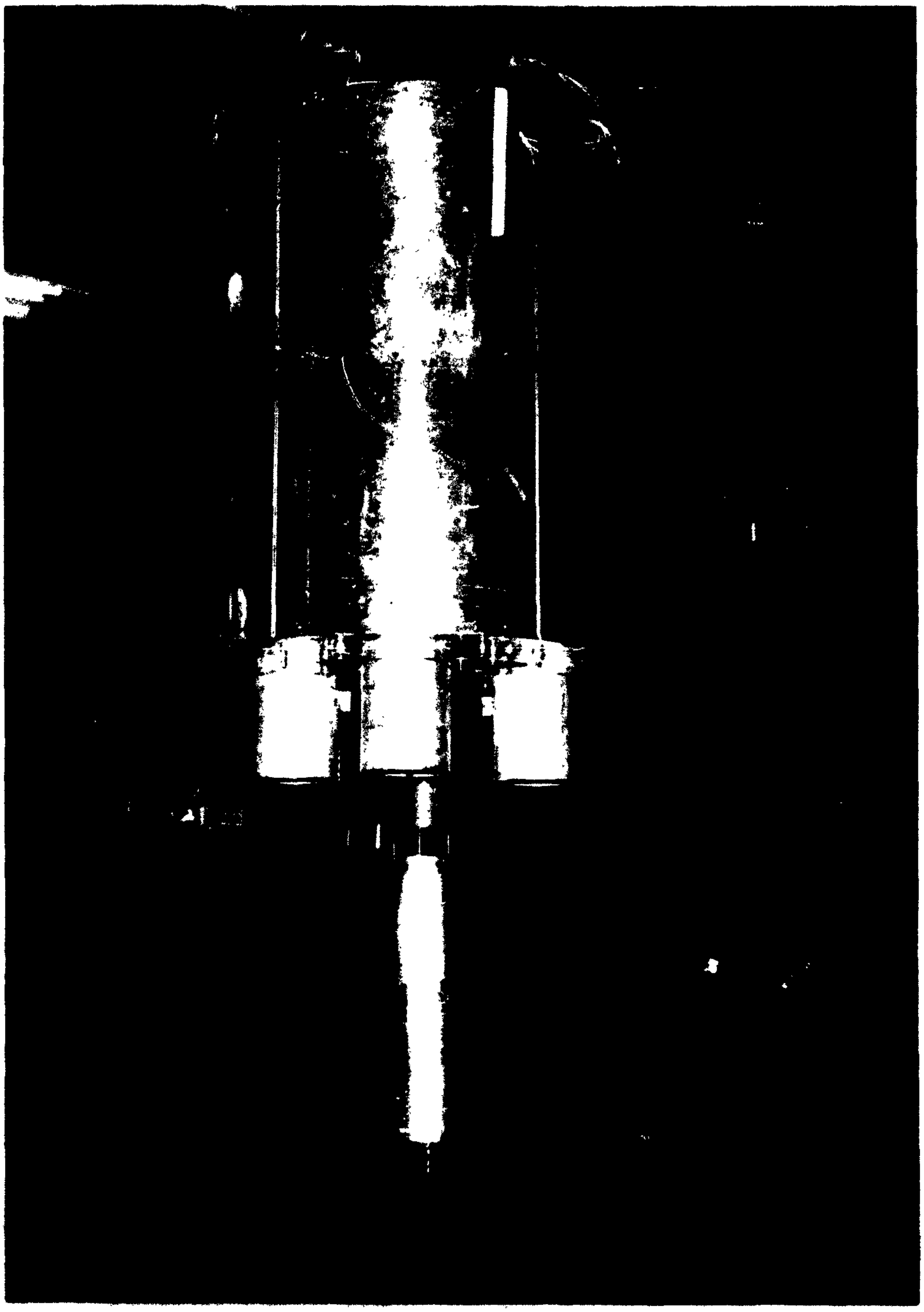
B. First Refractometer Drop

The results obtained with the small balloon above 15,000 feet were not encouraging if one assumes the position that the observed variations in this region are unreal. If the variations of the highly periodic nature were unreal, it is a near certainty that the sampling cavity has nearly lost control of the 400 Mc/s oscillator. Investigation revealed that the batteries being used for the heater supplies were not performing well at temperatures lower than room temperature. The batteries were not exposed and checks in an environmental chamber had indicated satisfactory operating time of 1 hour or more in the low temperature environment. Heater supply batteries were replaced with Nickel-Cadmium cells.

More control of the experiment was visualized if the refractometers could be dropped on command from say a height of 50,000 feet, one after the other. The Balloon R and D Test Branch, AFCRL, Holloman Air Force Base, gave excellent cooperation in the performance of this type experiment.

A container was constructed (Fig. 4) which held four refractometers. Each was to be commanded out in sequency by the Flight Controller. The refractometers and the control instrumentation were elevated with 45 feet diameter Raven poly balloons. A trajectory was planned that would carry the balloon near overhead at the receiver but nature did not cooperate in maintaining a stable wind vector at 50,000 feet. The trajectory on two flights allowed the package to come no closer than 20 miles from the receiver site. However, two refractometers were dropped, one on each of two flights. Data were recorded on each of these two flights at ranges varying from 20 to 35 miles.

The first flight of the refractometers was launched at Deming, New Mexico, and the receiver site was located at a point 20 miles south of Alamogordo, New Mexico. It was anticipated that four soundings would be made as the flight proceeded toward the receiver at a speed near 60 knots. Each refractometer was to reach the surface in from 12 to 15 minutes. The descent rate from 50,000 feet to 20,000 feet was limited by a small parachute which gave a speed of 9,000 feet/min. At 20,000 feet, the main parachute opened and the unit was lowered the remaining distance at a rate of 2,000 feet per minute.



REFRACTOMETER CONTAINER

FIG. 4.

At flight time and at the receiver site there was 3/10 cloud coverage, but by the time the first drop was to be made there was complete low cloud coverage. Nevertheless, it was decided to drop one refractometer. Fig. 5 shows that portion of this drop which was felt to be useful in this report. The profile is considered meaningful in observing layers from 50,000 feet down to near 25,000 feet. First note that the actual recorded profile resembles but little the mean profile normally obtained from temperature and pressure calculations. Consider that the refractometer left its container at a temperature considerably above the outside ambient temperature. Now plot a mean refractive index profile and thus fix an error in the recorded profile. This curve is indicated in Fig. 5. In order to obtain some validity for this error assume that the temperature of the cavity is given by[4]

$$\theta_f = (\theta_1 + \beta t) - \beta\tau \left(1 - \epsilon^{-\frac{t}{\tau}}\right) + (\theta_i - \theta_1)\epsilon^{-\frac{t}{\tau}}$$

where

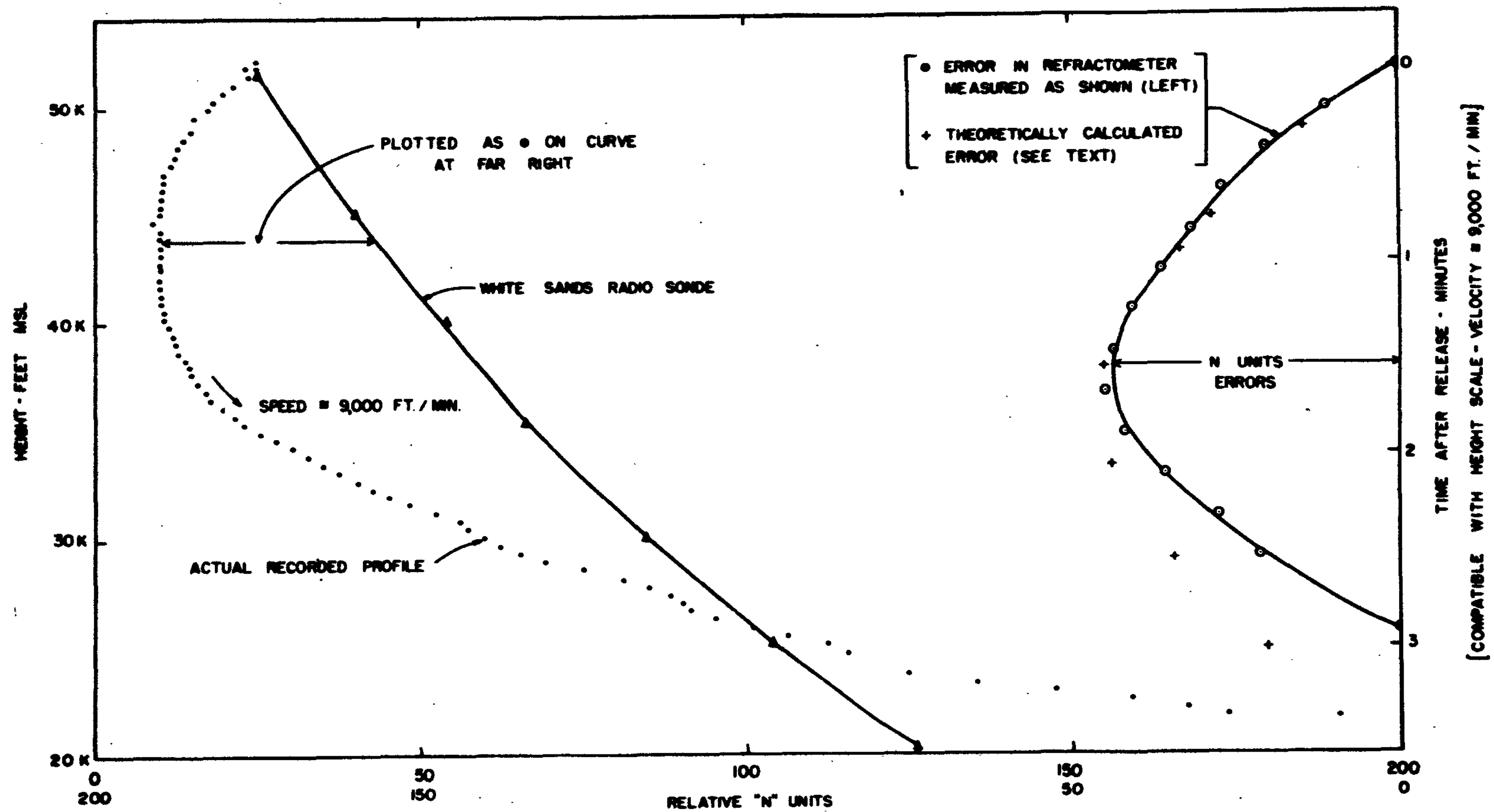
θ_f = cavity temperature at time t after drop

θ_1 = initial air temperature at top of profile

β = time rate of change of air temperature

τ = time constant

θ_i = cavity temperature at $t = 0$



E-A RECORDED PROFILE
31 JAN. 1963
FIG. 5.

A time constant and starting temperature may then be estimated by considering the initial slope of the error curve and the temperature variations obtained from radiosonde data. Solving two simultaneous equations will give a τ of 1.4 minutes and a starting temperature of 243°K, temperature data from the radiosonde, and a cavity temperature coefficient of 1 ppm/°F, then, the indicated points can be calculated.

One could attempt to fit the error curve with other time constants and starting temperature. However, it is not believed this is justified, particularly when all we wish to show is that the indicated profile is understood well enough to say that if there were departures from a smooth function, then such could be interpreted as departures from the mean profile.

Since the plot was obtained from an Esterline-Angus recording, only larger scale stratifications could be found in the profile. Certainly there are no layers present above 25,000 feet which are comparable in strength to those encountered at altitudes below 12,000 feet.

Consider further the interesting region between 40,000 and 45,000 feet. This is, no doubt, a region in which the cavity temperature variations nearly offset the change in cavity frequency due to change in index of refraction. Reference to the E-A chart in this region shows evidence of a small noise but certainly no greater than $\frac{1}{10}$ N unit. So it is reasonable to say that the value of spectral intensity at spatial wave numbers near 0.1 ft.$^{-1}$ is extremely small. Even these crude estimates

tend to indicate that variations in refractive index near 50,000 feet and occurring over small distances, say, less than 150 feet, will be quite small and possibly not be resolvable with present day refractometers.

It is not understood, presently, why the fine scale recording was "washed out" by noise in the region above 25,000 feet. This occurred for both the refractometers dropped from 50,000 feet and appears to be related to the velocity of fall. Very rapid variations occurred having a magnitude which coated the Brush recorder "solid" with ink. The profile of Fig. 5 is much quieter above 25,000 feet than that of Fig. 3, where it was indicated that there could have developed circuit difficulties in the refractometer.

Slightly below 25,000 feet, Fig. 5, it is felt that the refractometer encountered clouds and either began to form frost or liquid water within the interior of the cavity. The apparent profile was recorded to the surface and contained distinct evidence of wetting and drying within the cavity as the cavity entered and left the cloud regions. No further drops were made this day, because of the cloud cover, and the remaining refractometers were allowed to fall in the container.

C. Second Refractometer Drop

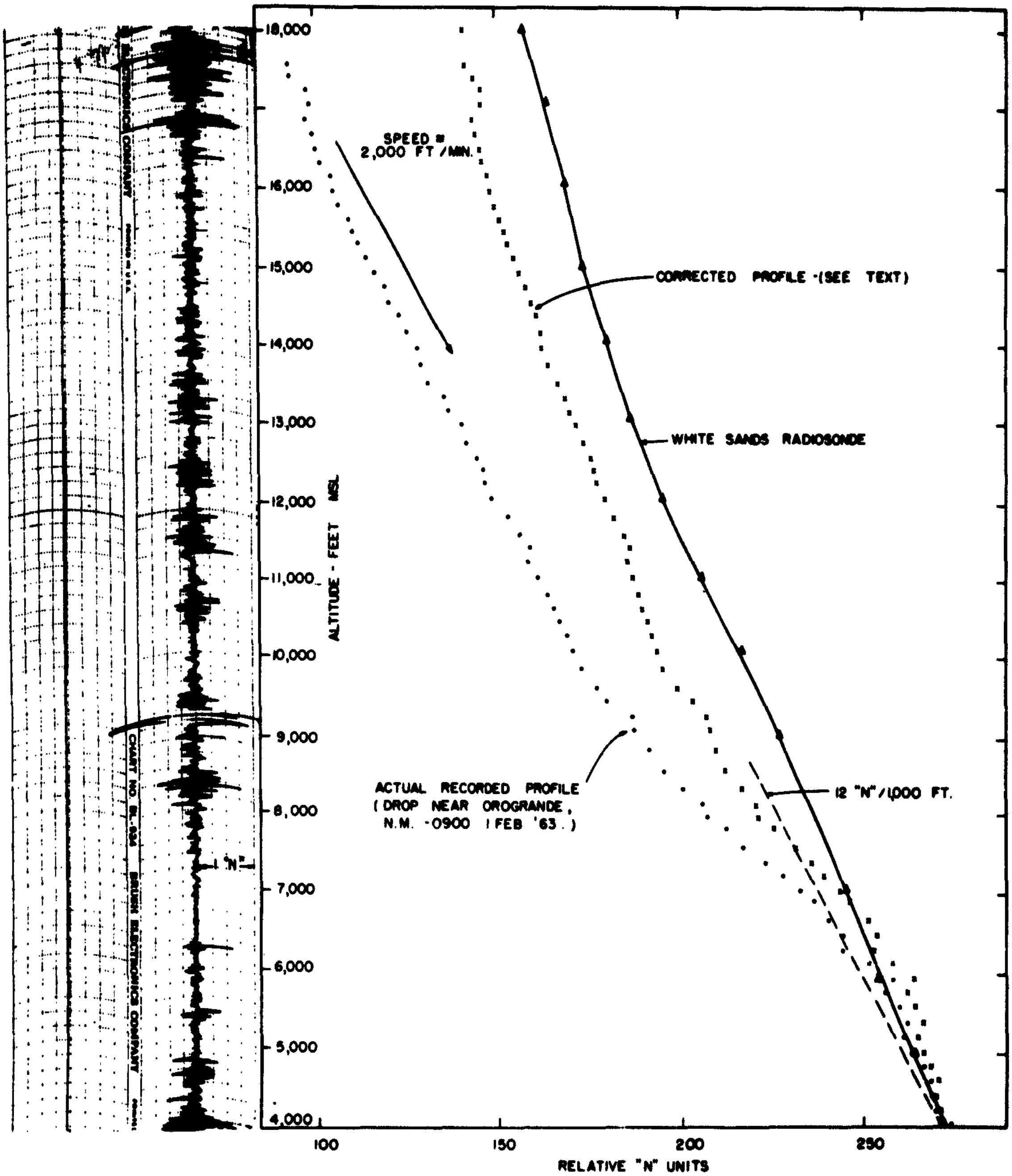
A second refractometer drop was planned and the launch point was moved to Arrey, New Mexico to attempt a trajectory closer to the receiver site. However, the balloon never reached a point closer than 20 miles away from the receiver site. A refractometer was released at

about the nearest approach of the balloon and the results of this drop are presented in Fig. 6. It is not possible to explain whey there is no data above the opening of the main parachute. The appearance of the high noise level at the drop velocity (9,000 ft/min) above 20,000 feet again seems to be suspected.

Good profile data were obtained below 18,000 feet simultaneously with the small scale variations. The manner of presentation of small scale data is different from Fig. 3 because of its having been recorded on magnetic tape. The tape has been played back at a speed to produce a length of tape compatible with reasonable graphing of the profile. The refractometer traversed no clouds during this particular sounding.

The noise level of the receiver was reduced to a value less than 0.05 N unit peak to peak for the recording of Fig. 6. A large amount of this was 60 cps and could be removed by filtering. Certainly this record shows that on this particular day there was no simple dependence of height in the excursions of the index of refraction from the mean profile, rather there appear to be "blobs" of moisture encountered in layers.

A corrected profile is constructed from a straight line variation in temperature. Actually the cavity temperature variation, near the top of the profile is not well predicted from air temperature data. The parachute opening at 18.8 thousand feet induced a transient into the cavity temperature variation which can only be estimated.



MICRO-VARIATIONS WITHIN PROFILE

FIG 6

IV. SUMMARY

An effort has been made to record continuously the fine structure of the atmospheric index of refraction profile. This was done with an MX-1(XH-1) AMQ refractometer elevated to heights of 50,000 feet. Sufficient information was obtained to state that:

1. There is no smooth trend in the fine structure of the profile to altitudes near 20,000 feet.
2. The measurements are compatible with those made to 20,000 feet with an aircraft installed X-band refractometer.[1]
3. It is not likely, with the present state of the refractometer art, that space variations, existing in refractive index at altitudes of the order 50,000, will be sufficiently resolved to construct a representative power density function. This is due basically to the apparently very small magnitude of the variations.
4. Enough evidence of profile construction is presented to show that correction of recorded profiles for cavity temperature variations is not a major problem. It is believed that reasonable accuracy in recording absolute index could be achieved particularly if the cavity temperature is measured.

Significant Level Data
White Sands Site

Station Altitude 3989 Feet MSL
Date: 1 Feb 1963, 0900 hrs MST
Ascension No. 75

WSTM Site Coordinates
E 488, 580 Feet
N 185, 045 Feet

Pressure Millibars	Geometric Altitude MSL Feet	Temperature Air Degrees	Temperature Dewpoint Centigrade	Relative Humidity Per cent
880.8	3989	14.9	2.8	44
837.0	5402	13.0	2.0	47
766.0	7827	8.0	-0.5	55
705.0	10064	4.7	-5.7	47
686.0	10800	7.2	-6.2	38
618.0	13605	4.1	-15.2	23
502.0	19029	-8.8	-21.6	35
488.0	19748	-10.2	-22.8	35
473.0	20539	-9.9	-35.9	10
439.0	22418	-13.4		
400.0	24718	-19.6		
324.0	29724	-33.6		
263.0	34421	-45.6		
216.0	38628	-57.5		
169.0	43617	-67.4		
154.0	45475	-64.6		
124.0	49792	-69.0		
100.0	54013	-71.0		
80.0	58309	-76.8		
77.0	59043	-72.2		
66.0	62029	-73.3		
62.0	63248	-70.0		
60.0	63902	-63.5		
56.0	65305	-62.4		
50.0	67601	-64.9		
33.0	76104	-58.4		
22.0	84514	-59.5		
18.0	88737	-52.5		
14.0	94089	-54.4		
10.0	101349	-47.0		
8.0	106262	-45.7		
7.0	109261	-38.0		
6.0	112811	-34.1		

TABLE I
White Sands Radiosonde

Significant Level Data
White Sands Site

Station Altitude 3989 Feet MSL
Date: 31 Jan 1963, 0900 hrs MST
Ascension No. 71

WSTM Site Coordinates
E 488, 580 Feet
N 185, 045 Feet

Pressure	Geometric Altitude MSL Feet	Temperature Air Degrees	Temperature Dewpoint Centigrade	Relative Humidity Per cent
884.7	3989	16.5	-0.2	32
859.0	4812	16.4	-3.7	25
801.0	6745	11.2	-4.9	32
754.0	8392	7.5	-4.6	42
693.0	10656	3.2	-12.8	30
663.0	11834	3.0	-5.2	55
632.0	13105	0.9	-9.4	46
565.0	16029	-5.6	-21.3	28
541.0	17146	-6.4	-33.1	10
494.0	19460	-11.3	-28.9	22
427.0	23073	-20.5	-24.8	69
400.0	24655	-23.5	-29.4	59
375.0	26198	-26.7	-34.6	48
337.0	28700	-33.7	-38.5	63
327.0	29393	-35.2	-42.5	48
283.0	32653	-43.2	-50.0	48
192.0	40850	-64.9		
166.0	43724	-72.0		
160.0	44441	-71.0		
151.0	45588	-64.6		
122.0	49867	-66.1		
100.0	53787	-72.0		
94.0	54988	-72.7		
85.0	56975	-64.9		
75.0	59476	-67.9		
67.0	61729	-65.2		
50.0	67576	-67.9		
39.0	72627	-58.2		
25.0	81847	-59.7		
10.0	101137	-52.0		
6.0	112204	-47.9		

TABLE II
White Sands Radiosonde

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